U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-260 375

Evaluation of Flow Equalization at a Small Wastewater Treatment Plant

Johnson and Anderson, Inc, Pontiac, Mich

Prepared for

Municipal Environmental Research Lab, Cincinnati, Ohio Wastewater Research Div

Sep 76

335082

PB 260 375

EPA-600/2-76-181
September 1976

Environmental Protection Technology Series

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into five series. These five broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The five series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment, and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA-600/2-76-181		

4. TITLE AND SUBTITLE	5. REPORT DATE
EVALUATION OF FLOW EQUALIZATION AT A SMALL WASTEWATER TREATMENT PLANT	September 1976 (Issuing Date)
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Gerald W. Foess, James G. Meenahan and J. Michael Harju	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Johnson & Anderson, Inc. P. O. Box 1166 - 2300 Dixie Highway Pontiac, Michigan 48056	10. PROGRAM ELEMENT NO. 1BB033
	11. CONTRACT/GRANT NO. 68-03-0417
12. SPONSORING AGENCY NAME AND ADDRESS Municipal, Environmental Research Laboratory Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268	13. TYPE OF REPORT AND PERIOD COVERED Final
	14. SPONSORING AGENCY CODE EPA-ORD

15. SUPPLEMENTARY NOTES

16. ABSTRACT

The primary objective of this project was to evaluate the impact of flow equalization on the 0.092 m^3/sec (2.1 mgd) activated sludge plant at Walled Lake/Novi, Michigan. Process streams were characterized for a twelve-month period under equalized flow conditions with respect to BOD, total suspended solids and total phosphorus. The effects of the equalization basin on final settling and filtration were evaluated by conducting two intensive week-long studies, one with and one without equalization of flow.

Flow equalization was effective in leveling influent flow variations but had very little effect upon concentration leveling. Performance of the multimedia filters was superior under the equalized flow, both in terms of average removal efficiency and consistency.

This report was submitted in partial fulfillment of Contract Number 68-03-0417 by Johnson & Anderson, Inc. under the sponsorship of the Environmental Protection Agency.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Waste Treatment, Wastewater, Flow Control, Cost Comparison	Wastewater Treatment *Flow Equalization	13B

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report)	21. NO. OF PAGES
Release to Public	UNCLASSIFIED	60
	20. SECURITY CLASS (This page) UNCLASSIFIED	22. PRICE $4.50/3.00

EPA Form 2220-1 (9-73)

1a

*USGPO: 1976 — 757-056/5412 Region 5-11

EPA-600/2-76-181
September 1976

EVALUATION OF FLOW EQUALIZATION AT A SMALL WASTEWATER TREATMENT PLANT

by

Gerald W. Foess
James G. Meenahan
J. Michael Harju
Johnson & Anderson, Inc.
Pontiac, Michigan 48056

Contract No. 68-03-0417

Project Officer
Ben W. Lykins, Jr.
Wastewater Research Division
Municipal Environmental Research Laboratory
Cincinnati, Ohio 45268

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

i h

DISCLAIMER

The Municipal Environmental Research Laboratory has reviewed this report and approved its publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

This report provides a documentation of the operation and an evaluation of the impact of flow equalization as it is applied to a small municipal wastewater treatment plant.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

ABSTRACT

The primary objective of this project was to evaluate the impact of flow equalization on the 0.092 m^3/sec (2.1 mgd) activated sludge plant at Walled Lake/Novi, Michigan. Process streams were characterized for a twelve-month period under equalized flow conditions with respect to BOD, total suspended solids and total phosphorus. The effects of the equalization basin on final settling and filtration were evaluated by conducting two intensive week-long studies, one with and one without equalization of flow.

Flow equalization was effective in leveling influent flow variations but had very little effect upon concentration leveling. Performance of the multimedia filters was superior under the equalized flow, both in terms of average removal efficiency and consistency.

This report was submitted in partial fulfillment of Contract Number 68-03-0417 by Johnson & Anderson, Inc. under the sponsorship of the U. S. Environmental Protection Agency.

CONTENTS

Section	Title	Page
I	CONCLUSIONS	1
II	RECOMMENDATIONS	3
III	INTRODUCTION	4
	Need for Study	4
	Scope and Objectives	4
IV	PLANT DESCRIPTION	6
	General	6
	Design Criteria	6
	Influent Characteristics	9
	Plant Performance	9
	Chemical Treatment	12
V	EQUALIZATION SYSTEM	14
	Selection of System	14
	Design Considerations	16
	General	16
	Sizing the Basin	16
	Air and Mixing Requirements	19
	Pumping	21
	Flow Metering	21
	Operation and Control	21
VI	EXPERIMENTAL PROCEDURES	23
	Sampling	23
	Analyses	23
	Plant Operation	23

Section	Title	Page
VII	RESULTS AND DISCUSSION	25
	Performance of Equalization Basin	25
	Flow Leveling	25
	Concentration Leveling	25
	Mass Leveling	25
	Effects of Equalization on Influent Wastewater Characteristics	25
	Total Suspended Solids (TSS)	29
	BOD_5	29
	Soluble Orthophosphate	29
	Ammonia Nitrogen	30
	Effects of Equalization on Plant Processes	30
	Activated Sludge - Final Settling	30
	Filtration	35
VIII	COST CONSIDERATIONS	40
	General	40
	Equalization Basin	41
	Pumping	41
	Aeration	44
	Chemical Feeding	45
	Manpower Requirements	45
IX	REFERENCES	46

LIST OF FIGURES

Number		Page
IV-1	Treatment Schematic-Walled Lake/Novi, Michigan	7
V-1	Schematic Flow Diagrams of Typical Equalization Systems	15
V-2	Cross-Sectional View of Walled Lake/Novi Equalization Basin	17
V-3	Typical Flow Variation - Walled Lake/Novi, Michigan	18
VII-1	Treatment Plant Flow Charts - Walled Lake/Novi, Michigan	26
VII-2	Effects of Equalization on Concentration Leveling	27
VII-3	Effects of Flow Equalization on Mass Leveling	28
VII-4	Mass Diagram - Final Clarifier Effluent	33
VII-5	Effect of Equalization on Secondary Effluent BOD_5 and TSS	36
VII-6	Mass Diagram - Filter Effluent	37
VII-7	Effect of Equalization on Filter Effluent BOD_5 and TSS	39

LIST OF TABLES

Number		Page
IV-1	Summary of Design Criteria	8
IV-2	Discharge Concentration Limitations	9
IV-3	Summary of Raw Wastewater Characteristics	10
IV-4	Summary of Plant Performance	11
IV-5	Summary of Plant Operating Parameters	13
V-1	Requirements for Aerating and Mixing Raw Wastewater	20
VII-1	Effects of Equalization on Wastewater Parameters	29
VII-2	Plant Performance Summary	31
VII-3	Summary of Operating Parameters During Testing Periods	32
VIII-1	Construction Cost - Walled Lake/Novi Equalization Basin	42
VIII-2	Construction Cost - Walled Lake/Novi Wastewater Treatment Plant	43

ACKNOWLEDGEMENTS

The investigators at Johnson & Anderson, Inc., would like to express their appreciation for the assistance and cooperation received from Mr. M. M. Corwin, Superintendent of the Oakland County Water and Sewer Department, from personnel at the Walled Lake/Novi treatment plant, and from Mr. David Blough who performed the laboratory analyses.

Sincere gratitude is also expressed for the support and counsel of Mr. John M. Smith and Mr. Ben Lykins, Municipal Environmental Research Laboratory, U. S. Environmental Protection Agency, Cincinnati, Ohio.

LIST OF ABBREVIATIONS

BOD	5-day biochemical oxygen demand
cfm	cubic feet per minute
cm	centimeter
cu	cubic
ft	feet
gal	gallon
gpd	gallons per day
gpm	gallons per minute
kg	kilogram
kw	kilowatt
kwh	kilowatt hour
l	liter
lb	pound
m	meter
mm	millimeter
mgd	million gallons per day
mg	milligram
min	minute
ml	milliliter
P	phosphorus
SOP	soluble orthophosphate
SRT	solids retention time
sq	square
SDI	sludge density index
SVI	sludge volume index
TSS	total suspended solids

SECTION I

CONCLUSIONS

1. The Walled Lake/Novi equalization system is highly effective in leveling influent flow variations and providing a uniform flow rate to the process units (Section VII, Page 25).
2. The Walled Lake/Novi equalization system is not effective in concentration leveling; that is, both the raw and equalized wastewater exhibit similar diurnal variations in strength. Some mass leveling occurs, but it is due more to flow rate equalization than it is to wastewater blending (Section VII, Page 25).
3. For the underloaded Walled Lake/Novi secondary clarifier, peak overflow rate = 20.4 m^3/m^2- day (500 gpd/sq ft.), variations in flow rate are apparently not as important as other variables such as mixed-liquor settleability, wind and density currents, etc., in determining effluent quality and percentage removal efficiency. This was evidenced by (a) the similar removals of total suspended solids (TSS) and BOD_5 that were obtained with and without equalized flow, and (b) the lack of sensitivity of final clarifier performance to variations in overflow rate (Section VII, Page 35).
4. Based upon intensive testing conducted during two week-long periods, filter performance under an equalized mode was superior to performance under a diurnal flow mode, even though the filter was operated at an average rate of only 58.7 m^3/m^2 day (1 gpm/sq ft.) during both conditions. Moreover the better performance was achieved despite the fact that the filter influent TSS concentration was higher and more variable during the equalized flow period (Section VII, Page 39).

and operating characteristics of the selected pumps (Section V, Page 16).

5. Equalization tanks should be aerated to help maintain aerobic conditions and to aid in conditioning the sewage for downstream processes. If sufficient mixing is provided, sludge scraping mechanisms are unnecessary (Section V, Page 21).
6. Manual control of diffused air flow to an equalization basin is unsatisfactory because the variable liquid level in the tank affects the air flow rate, leading either to inefficient air usage or to frequent adjustment of a control valve; there is also the potential for surge or overload of the blower system if the manual valve is not adjusted properly (Section V, Page 19).
7. Experience is necessary to accurately forecast the average daily flow rate so that the equalization controls can be properly set. Even with experience, adjustments may be necessary periodically to avoid overflowing or emptying of the tank (Section V, Page 22).
8. Even if equalization is provided, it may be desirable to design chemical feed systems with flow-proportional control to automatically compensate for adjustments that are periodically made to the equalized flow rate (Section IV, Page 12 and Section VIII, Page 45).
9. A theoretical analysis of power costs for pumping at the Walled Lake/Novi Wastewater Treatment Plant led to the following conclusions:
    a. Total power costs for pumping design flow with side-line flow equalization would be only marginally (less than two percent) higher than for the same plant operating without equalization.
    b. Power rate schedules which penalize peak demands with a high demand charge component may improve the cost effectiveness of flow equalization (Section VIII, Page 41).
10. Based upon power usage data during the testing period, the presence of equalization has very little impact on overall power consumption at the Walled Lake/Novi Wastewater Treatment Plant (Section VIII, Page 41).
11. At Walled Lake/Novi, the presence of an equalization system does not appreciably simplify plant operation, but neither does it add significantly to manpower operational requirements, except for potential major repairs to pumps, controls, or air compressors (Section VIII, Page 45).

SECTION II

RECOMMENDATIONS

1. Flow equalization should always be evaluated for use upstream of granular media filters which would otherwise be subjected to variable flows.
2. If a diffused aeration system is used in an equalization unit, preference should be given to a centrifugal blower with an automatic control valve tied to the basin liquid level (Conclusion 7, Page 2).
3. A diffused air input of 0.167 - 0.250 $l/s/m^3$ is adequate for mixing an equalization basin, but further studies are needed to establish the optimal air requirement.
4. More information is needed on primary and secondary clarifier performance under hydraulically stressed conditions with and without flow equalization. This information is needed before the cost effectiveness of equalization basins can be fully assessed.

SECTION III

INTRODUCTION

Need for Study

Several benefits have been ascribed by various investigators (1,2,3,4) to the use of flow equalization in wastewater treatment systems. The most notable of these are the following:

1. Equalization improves performance of sedimentation basins by dampening hydraulic variations and reducing peak flow rates; in so doing, it permits smaller requisite clarifier sizes in new plant design or increases capacity of existing units.
2. It benefits biological treatment by producing increased uniformity in the concentration and flux of organics and nutrients in the wastewater, as well as more stable retention periods in the aeration basin.
3. It simplifies manual and automated control of flow-rate dependent operations, such as chemical feeding, disinfection, sludge pumping, etc.
4. It improves treatability and provides some BOD reduction and odor removal (if aeration is used for mixing in the equalization basin).
5. It provides a point of return for recycling concentrated waste streams, thereby mitigating shock loads to primary settlers or aeration basins.

Despite the above advantages, flow equalization has not been widely applied in the municipal pollution control field because of uncertainties in the areas of cost effectiveness and operating problems. Additionally, there is a lack of plant operating data to document the magnitude of beneficial effects. One pilot plant study (5), for example, failed to show that equalization had any effect on the 24-hour composite BOD removal of an activated sludge system.

Scope and Objectives

This report describes the results of a brief study of an equalization system at the Walled Lake/ Novi Wastewater Treatment Plant in Novi, Michigan. The plant is a new 0.092 m^3/sec (2.1 mgd) tertiary facility which utilizes the activated sludge process followed by multimedia tertiary filters to meet stringent effluent

quality standards. Process streams were characterized from plant data for a twelve-month period under equalized flow conditions with respect to BOD, total suspended solids (TSS) and total phosphorus (TP). In addition, two intensive week-long studies, one with and one without equalization of flow, were conducted to determine the effects of the equalization basin on final settling and filtration processes, and to provide data concerning performance of the equalization basin itself.

The work reported herein developed as an offshoot of more comprehensive studies which the authors are conducting at the Ypsilanti Township (Michigan) Wastewater Treatment Plant. As such, this work should be considered supplemental in nature; its limited objective is to provide additional information on full-scale equalization systems so that the general applicability of flow equalization can ultimately be determined.

SECTION IV

PLANT DESCRIPTION

General

All incoming wastewater at the Walled Lake/Novi Wastewater Treatment Plant flows into a wet well. Large solids are removed with a stationary bar screen located at the entrance to the wet well. Process flow is pumped from the wet well to the plant at the estimated average daily flow rate; raw wastewater flow in excess of the average is pumped from the wet well to the equalization basin from which point it eventually flows back to the wet well by gravity during low flow periods. An automatic valve controls the discharge from the equalization basin so as to maintain a uniform process pumping rate. From the grit chamber, wastewater flows by gravity through the remainder of the plant treatment processes which consist, respectively, of aeration, final settling, chlorination and filtration. Alum and polyelectrolyte are added to the effluent of the aeration basins for phosphorus removal.

Settled solids from the final settling tank are pumped to an aerobic digester. The digested sludge is decanted, pumped to drying beds and ultimately trucked to a landfill. Digester supernatant and filter backwash water are returned to the influent wet well.

A schematic flow diagram of the plant is given in Figure IV-1.

Design Criteria

Plant design criteria are summarized in Table IV-1. Despite the inclusion of flow equalization in the system, conservative process design loadings were required by the regulatory agency to help ensure that stringent effluent standards would be met .

It was known that initial flows at the plant would be small in relation to the design value. Hence, the aeration basins and final settlers were designed in three independent modular units to be constructed in stages.

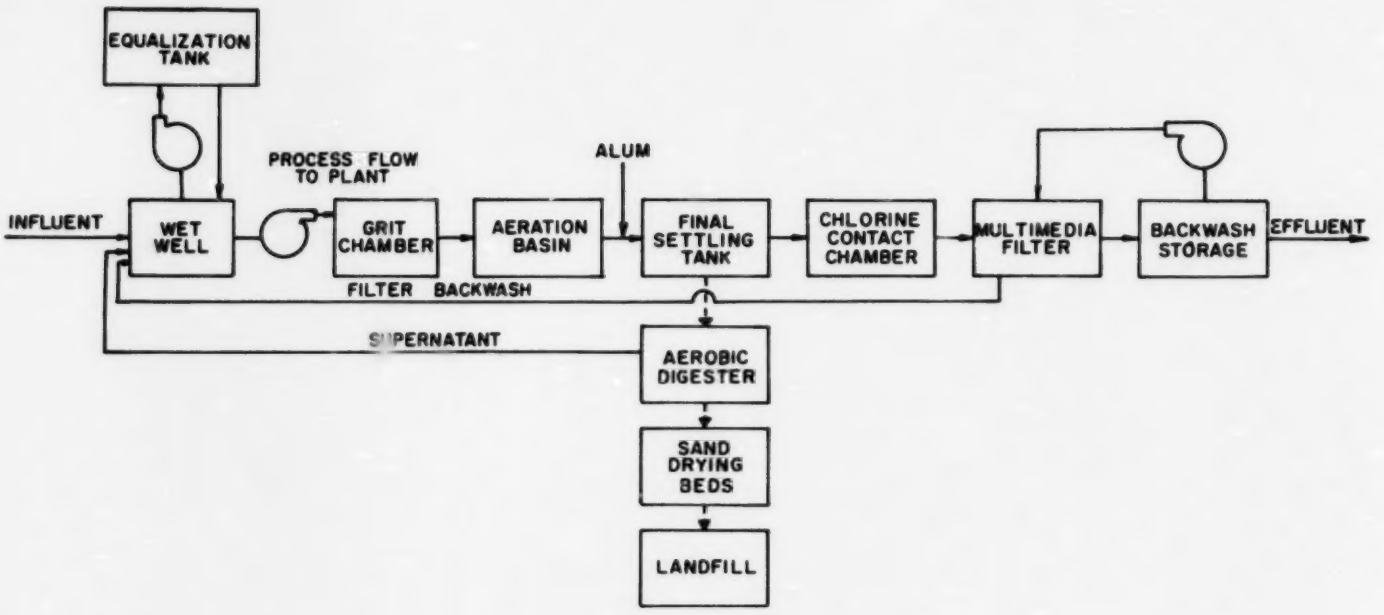


FIGURE IV-1. TREATMENT SCHEMATIC - WALLED LAKE/NOVI, MICHIGAN

TABLE IV-1

SUMMARY OF DESIGN CRITERIA

WALLED LAKE/NOVI, MICHIGAN

Item	Value: Metric Units	English Units
Average Dry-Weather Flow	0.092 m^3/sec	2.1 mgd
BOD Loading	1630 kg/day	3600 lb/day
TSS Loading	1905 kg/day	4200 lb/day
Equalization Basin (1 unit)		
Volume	1,275.5 m^3	337,000 gal
Maximum Water Depth	4.57 m	15 ft
Applied Air	0.015m^3/min/m^3	15 cfm/1000 cu ft of basin volume
Aeration Basins (3 units)*		
BOD Loading	0.57 kg/m^3 day	35 lb/1000 cu ft/day
Volume per Unit	961 m^3	254,000 gal
Detention Time	8.7 hours	8.7 hours
Flow Regime - Complete Mix		
Final Settling Basins (3 units)*		
Diameter	15.24 m	50 ft
Overflow Rate at Average Flow	14.7 m^3/m^2 day	360 gpd/sq ft
Depth	4.57 m	15 ft
Multimedia Filters (4 units)**		
Area per Unit	18.2 m^2	196 sq ft
Loading Rate at Average Flow	109.8 m^3/m^2 day	1.86 gpm/sq ft
Depth of Media	762 mm	30 in
Media Composition (% by weight)		
4.2 sp. gr. Material	15	15
2.6 sp. gr. Material	30	30
1.5 sp. gr. Material	55	55
Depth of Support Gravel		
High Density Gravel	76.2 mm	3 in
Silica Gravel	304.8 mm	12 in
Backwash Rate	880 m^3/m^2 day	15 gpm/sq ft
Rotary Surface Wash Rate	41.1 m^3/m^2 day	0.7 gpm/sq ft

* Only two of the three aeration and settling units have been constructed and only one unit was in use during the study.

** Only two of the four filter units were operated during the study.

During the study, only one of the modular units was in use. Similarly, only two of four filters were employed. Actual process loadings obtained during the study period are discussed later in the report.

The effluent standards to be met by the plant, as given by the plant's NPDES Permit, are summarized in Table IV-2 below:

TABLE IV-2

DISCHARGE CONCENTRATION LIMITATIONS

WALLED LAKE/NOVI, MICHIGAN

Parameter	30-Day Average	7-Day Average	Daily Maximum
BOD_5 (mg/l)	--	--	10
TSS (mg/l)	10	15	--
NH_3-N (mg/l)	--	--	2.0
Total P	20% of Influent Conc.	--	--
Fecal Coliform	200/100 ml	400/100 ml	--

The stringent requirements for suspended solids removal are what dictated the need for filtration of secondary effluent at the plant. Equalization was provided principally to ensure a constant flow through the gravity filters; additional factors related to selection of equalization are discussed in Section V.

Influent Characteristics

Walled Lake/Novi wastewater is primarily of domestic origin. A summary of flow and strength variations over the 14-month period ending February, 1975, is given in Table IV-3. Observation of the table reveals that flows were higher during the months of January through May, indicating an infiltration/inflow problem. However, there is also evidence that the City's infiltration/inflow correction program is producing results. For example, peak flows during January and February, 1975, were lower than during the corresponding period in 1974 despite an increased service population. Moreover, sewage strength increased significantly during the period, reflecting the reduced extraneous flows.

Plant Performance

Part of this study involved compilation and examination of existing plant data to gain insight into the effects of equalization on plant processes. Some of the observations from this examination are presented in this section. The results of the detailed testing are presented in a later section.

TABLE IV-3

SUMMARY OF RAW WASTEWATER CHARACTERISTICS

WALLED LAKE/NOVI, MICHIGAN

Month	Average Daily Flow (mgd)*	Peak 24-Hr. Flow (mgd)*	Average Concentrations BOD_5 (mg/l)	TSS (mg/l)	Total-P (mg/l)
January, 1974	0.875	1.522	175	213	8.4
February	0.879	1.949	141	161	6.5
March	1.088	1.838	116	135	5.2
April	1.002	1.287	127	119	5.9
May	0.889	1.199	162	149	6.1
June	0.686	0.808	185	129	7.3
July	0.637		225	168	8.0
August	0.609	0.697	217	203	10.0
September	0.620	0.715	236	189	10.3
October	0.586	0.644	297	205	10.3
November	0.593	0.644	399	184	10.2
December	0.624	0.715	310	205	9.4
January, 1975	0.820	1.154	305	170	8.0
February	0.803	1.470	290	194	7.5

* mgd x 0.04381 = m^3/sec

A summary of plant influent and performance data for the 12-month study period is given in Table IV-4. During this time the plant was operated under equalized flow conditions, with the exception of the one week testing program October 28 through November 3, 1974, when the equalization tank was not used. The data indicate that both clarifier and filter performance were uniformly excellent throughout the period, except for January and February when performance temporarily deteriorated. Data which became available after the study period showed that plant performance had again improved to earlier levels.

Closer observation of Table IV-4 reveals that removal efficiencies through secondary clarification averaged 95, 94 and 82 percent for BOD_5, TSS and P, respectively. Removal efficiencies through final filtration averaged 97 percent for BOD_5 and TSS, and 84 percent for P. The latter figures indicate that the multimedia filter produced a very marginal improvement in effluent quality. Based upon the material that was applied to them, the filters removed only 39 percent of the BOD_5, 50 percent of the TSS and 13 percent of the applied TP. However, the filter effluent quality was very similar to results reported in the literature (6).

In interpreting the preceding results, it is instructive to examine the process loadings and other operating parameters during the period. These values are sum-

TABLE IV-4

SUMMARY OF PLANT PERFORMANCE

WALLED LAKE/NOVI, MICHIGAN

Item	Month 1974-75 Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	12-Month Average
Average Flow Rate (mgd)*	1.088	1.002	0.889	0.686	0.637	0.609	0.620	0.586	0.593	0.624	0.820	0.803	0.75
Raw Influent Quality (mg/l)													
BOD	116	127	162	185	225	217	236	297	399	310	305	290	239
TSS	135	119	149	129	168	203	189	205	184	205	170	194	171
P	5.2	5.9	6.1	7.3	8.0	10.0	10.3	10.3	10.2	9.4	8.0	7.5	8.2
Clarifier Effluent Quality (mg/l)													
BOD	14	15	10	9	11	9	8	8	11	13	18	29	13
TSS	12	12	10	8	8	11	10	10	8	11	11	12	10
P	1.0	0.9	1.0	1.0	1.7	3.1	2.2	1.7	1.5	1.1	1.1	1.1	1.5
Filter Effluent Quality (mg/l)													
BOD	8	8	6	5	6	5	5	6	7	9	14	22	8
TSS	7	6	5	4	4	5	4	4	3	5	5	6	5
P	0.8	0.7	0.8	0.9	1.6	2.8	2.0	1.7	1.1	0.8	1.0	0.9	1.3

* mgd x 0.04381 = m^3/sec

marized in Table IV-5 for a 12-month period. It is evident that all of the process units operated well within conventional design loadings. It may be that the performances of treatment processes at such low loadings are not sensitive to diurnal flow variations and that plant performance would have been equally high without equalization. Thus, it is not possible to attribute the exceptional plant performance solely to the beneficial effects of equalization.

Chemical Treatment

This plant is equipped with a chemical feed system for phosphorus removal. The system was originally designed for flexible operation as follows:

1. Application of ferrous chloride to the aerated grit chamber;
2. Application of lime to the splitting chamber, located just upstream from the aeration basins;
3. Application of polyelectrolyte either upstream of final sedimentation or prior to filtration as a filter aid.

After a period of experimentation, it was decided to use liquid alum rather than ferrous chloride as the primary coagulant for economic reasons. In addition, the point of alum application was changed to the effluent trough of the aeration basin, presumably to alleviate some foaming problems which had occurred in the aeration basin. Application of the lime and polyelectrolyte has not been needed and has not been carried out except for the initial trial.

All chemical feed pumps have variable speed drive and, despite the equalized flow, are equipped with an automatic control system which paces the dosage to flow rate. This feature eliminates the need for manual readjustment of the alum feed rate when the equalized process flow rate is changed.

An Al:P weight ratio of about 1.6:1 is used to provide requisite phosphorus removal. In order to maintain the proper ratio, the alum dosage is regulated based on the influent phosphorus concentration.

TABLE IV-5

SUMMARY OF PLANT OPERATING PARAMETERS

WALLED LAKE/NOVI, MICHIGAN

Month 1974-75

Item	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	12-Month Average
Activated Sludge System													
Detention Time (hrs)	5.6	6.1	6.9	8.9	9.6	9.9	9.8	10.4	10.3	9.9	7.7	8.5	8.6
Sludge Age (days)	4.2	5.7	5.1	7.3	6.1	6.4	6.0	5.8	5.9	5.8	5.7	6.9	5.9
F/M	--	--	--	--	--	0.35	0.34	0.45	0.63	0.49	0.57	0.44	0.47
MLSS (mg/l)	2440	2713	2668	2534	2550	2490	2536	2370	2370	2508	2514	3144	2570
MLVSS (mg/l)[1]	--	--	--	--	--	1474	1686	1505	1517	1571	1672	1970	1628
SDI	2.6	2.4	2.4	2.2	--	2.5	2.4	2.5	2.3	1.9	1.7	1.6	2.2
Final Clarifier Overflow Rate[2] (gpd/sq ft)	554	510	453	350	325	310	316	299	302	318	418	409	380
Effluent Filter Flow Rate[3] (gpm/sq ft)	1.9	1.8	1.6	1.2	1.1	1.1	1.1	1.0	1.2	1.2	1.5	1.4	1.3

[1] MLVSS was not measured prior to August, 1974; therefore. values for these parameters could not be computed.

[2] gpd/sq ft x .04074 = m^3/m^2 day

[3] gpm/sq ft x 58.66 = m^3/m^2 day

$$F/M = \frac{\text{kg/day (lb/day) } BOD_5 \text{ to Aeration}}{\text{kg (lb) MLVSS under Aeration}}$$

$$\text{Sludge Age} = \frac{\text{kg (lb) MLSS under Aeration}}{\text{kg/day (lb/day) SS to Aeration}}$$

$$SDI = \frac{\text{MLSS (mg/l)}}{\text{ml settled sludge} \times 10} = \frac{100}{SVI}$$

SECTION V

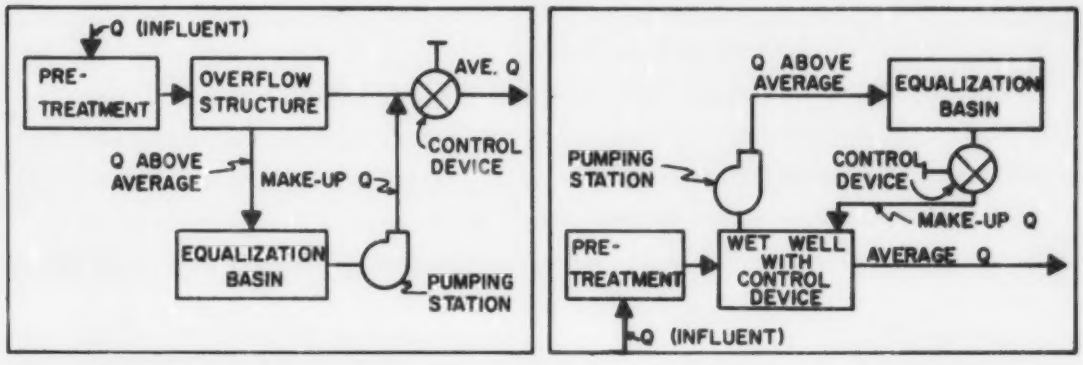
EQUALIZATION SYSTEM

Selection of System

Flow equalization was used at the Walled Lake/Novi Wastewater Treatment Plant for the following principal reasons: (i) it was considered that constant rate filtration would provide a superior effluent to filtration under diurnally varying rates, for the same filter area; (ii) it was determined that the cost of providing flow equalization would be nearly offset by the savings involved in sizing the filters based on average, rather than peak, flow rates; (iii) it was felt, based upon information available at the time, that equalization would have a beneficial effect upon the activated sludge and final settling processes.

It was also decided to use a "side-line" equalization system for this plant, as opposed to the "in-line" type. In the in-line design, all of the flow passes through the equalization basin, whereas in the side-line scheme, only that amount of flow above the average daily flow is diverted through the equalization basin. This basic difference is illustrated schematically in Figure V-1, which also shows the gravity and pumped alternatives which may be used for either in-line or side-line systems, depending on plant hydraulics, site topography and subsurface conditions.

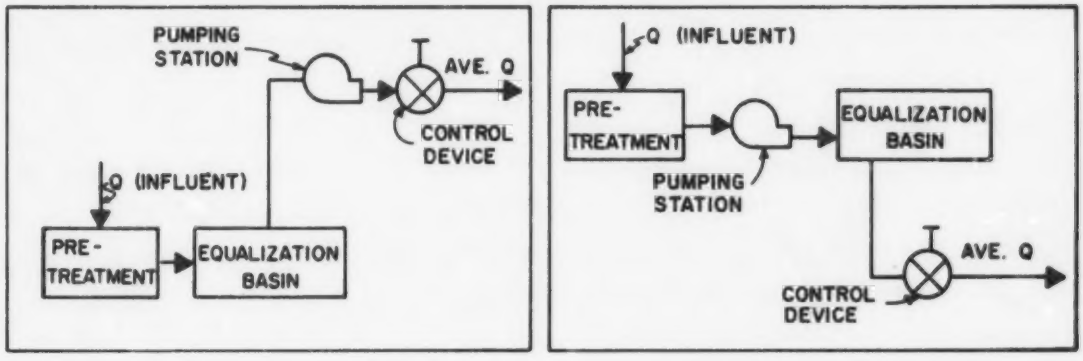
Side-line systems are generally, but not exclusively, applicable where flow through the plant is by gravity. In this instance, the smaller pumping requirements of the side-line scheme (i.e., only flows above the average daily flow) usually makes it more economical. On the other hand, if a raw sewage pumping station is required at the site anyway, an in-line system would minimize the flow to be pumped; in this case, the basin can be inserted after the pumping station and have gravity discharge to the process units, obviating the need for separate equalization pumps. However, the raw sewage pump motors would have to be sized to account for the additional head loss across the basin.



A) PUMPED FLOW FROM EQUALIZATION BASIN.

B) GRAVITY FLOW FROM EQUALIZATION BASIN.

SIDE-LINE EQUALIZATION



A) PUMPED FLOW FROM EQUALIZATION BASIN.

B) GRAVITY FLOW FROM EQUALIZATION BASIN.

IN-LINE EQUALIZATION

FIGURE V-1. SCHEMATIC FLOW DIAGRAMS OF TYPICAL EQUALIZATION SYSTEMS

There are, of course, individual circumstances at each plant site which may dictate selection of an equalization system apart from the generalizations mentioned above. At Walled Lake/Novi, for example, a side-line system was selected even though a raw sewage pumping station was required at the site. This selection was made because analysis showed that overall pumping costs would be minimized with the side-line system (even though the total amount of flow pumped would be greater). In evaluating these pumping costs, the considerations were as follows:

1. In-line system: Pump incoming diurnal flows to the equalization basin against a head of about 21.3 m (70 ft), with gravity discharge from the basin to the process units.
2. Side-line system: Pump incoming flows above the average daily flow to the equalization basin at a head of 11.6 m (38 ft), with gravity discharge back to the wet well; pump incoming flows at the average daily rate to the process units at an average head of 54 feet.

Another factor involved in selecting the type of equalization system to be used is the degree of concentration dampening desired. In-line systems are more effective for leveling variations in concentration because the entire flow passes through the basin.

Design Considerations

General. A simplified cross-sectional view of the Walled Lake/Novi equalization basin is shown in Figure V-2. It may be seen that the tank is equipped with a diffused air mixing system and a sludge scraping mechanism. Considerations involved in tank sizing, mixing and pumping are discussed in the following paragraphs.

Sizing the Basin. The storage volume required for flow equalization is equivalent to the cumulative flow above average occurring during the diurnal cycle. Various methods for determining this volume have been described elsewhere (2, 4) and will not be repeated here.

Figure V-3 illustrates a typical projected diurnal flow pattern at Walled Lake/Novi and the method of computing the requisite equalization basin volume. The computed storage volume of 1,230,125 l (325,000 gal) represents 15.4 percent of the design flow of 0.092 m^3/sec (2.1 mgd). As a rule of thumb, the authors have found that equalization basins for plants in the 0.04-0.22 m^3/sec (1-5 mgd) size range can be sized for 15 percent of the average daily volume flow, which

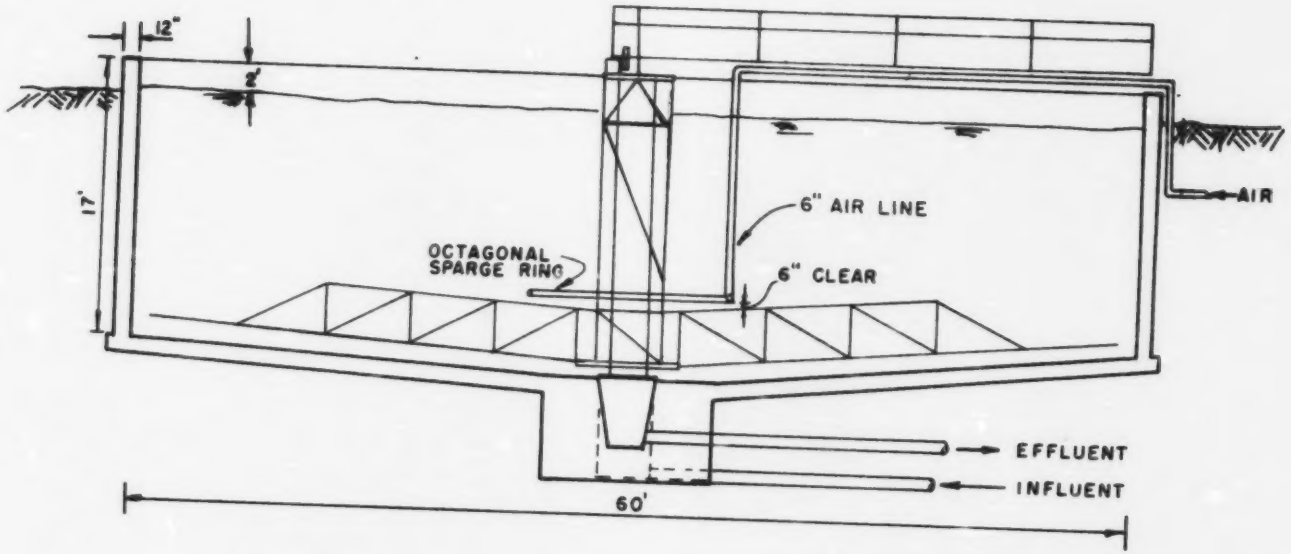


FIGURE V-2. CROSS-SECTIONAL VIEW OF WALLED LAKE/NOVI EQUALIZATION BASIN

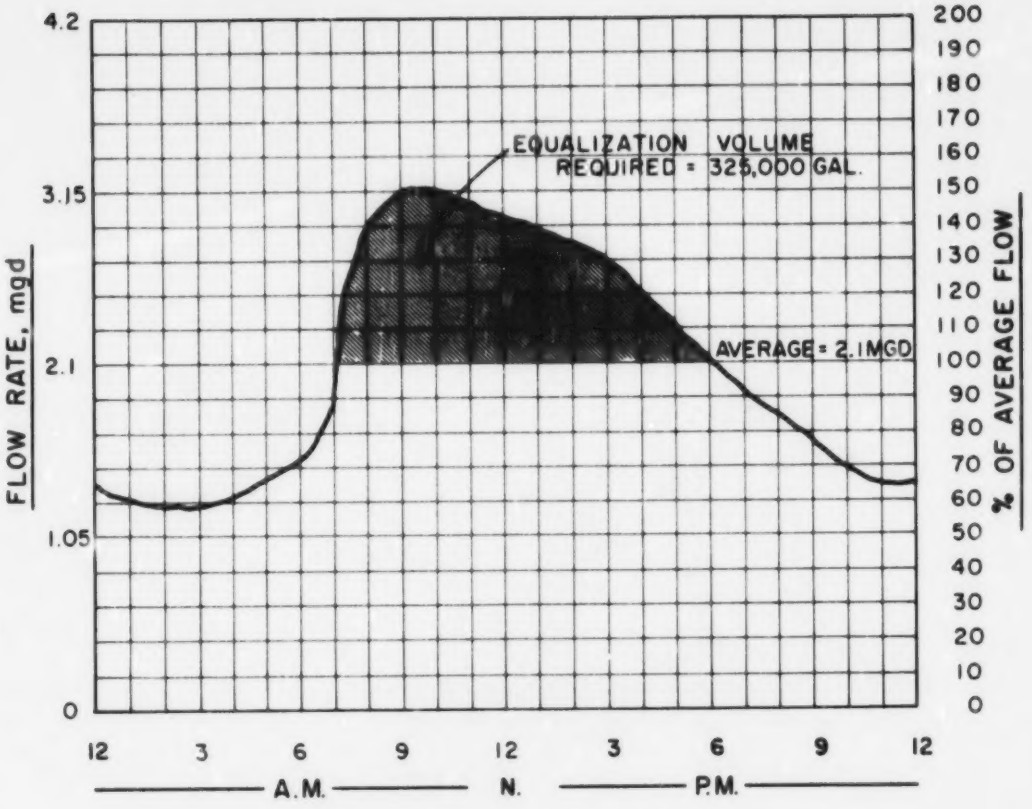


FIGURE V-3. TYPICAL FLOW VARIATION - WALLED LAKE/NOVI, MICHIGAN
(mgd x 0.04381 = m^3/sec; gal x 0.003785 = m^3)

is also the value used by Smith et al. (7). The correct volume will, of course, depend upon individual diurnal flow patterns which vary with population and other factors.

As constructed, the actual volume of the Walled Lake/Novi equalization basin at the maximum water depth is about 1,275.5 m^3 (337,000 gal). The nominal working volume is about 1,192 m^3 (315,000 gal) or 15 percent of the design dry-weather flow.

Air and Mixing Requirements. Diffused or mechanical aeration systems should be provided in an equalization basin to prevent septic conditions from developing. Aeration can also serve the dual purpose of blending the contents of the tank and preventing solids deposition, if these are desired objectives.

The minimum level of aeration required to prevent septicity and/or to provide complete mixing for an equalization basin is not well established. Table V-1 gives some values for sewage aeration and mixing requirements as derived from the literature. However, only reference (4) refers specifically to equalization basin requirements. The authors' recent experience with the Ypsilanti, Michigan equalization basin indicates that an air input of about 1.4 cfm/1000 gal of basin capacity (0.0104 $m^3/min/m^3$) is adequate.

The Walled Lake/Novi aeration system was designed to provide 2 cfm of air per 1000 gallons of storage (0.015 $m^3/min/m^3$) to the equalization tank. Based on a maximum nominal storage volume of 1,192 m^3 (315,000 gal) the air requirement is 17.8 m^3/min (630 cfm). Unfortunately, actual air input to the basin is not monitored separately and thus is not known.

Common compressors are used at the plant to serve not only the equalization basin but all other air-using processes at the plant. Control of air flow to the basin is accomplished by a manually operated valve. This system is not recommended since varying liquid levels in the equalization basin affect the air flow rate and frequent manual adjustment of the control valve is required to maintain a constant flow rate. If the control valve is not adjusted properly, air usage will be inefficient and there is the possibility of surge or overload of the blower system. Alternatively, an automatic control valve, which is regulated by the liquid level in the basin, can be used. Still another possibility is the use of a separate positive displacement air compressor for the equalization tank.

TABLE V-1

REQUIREMENTS FOR AERATING AND MIXING RAW WASTEWATER

To Maintain Aerobic Conditions	To Prevent Solids Deposition	Reference
1.25 to 2 cfm/1,000 gal. of storage	0.02 to 0.04 HP/1,000 gal. of storage	4
0.006 to 0.01 HP/1,000 gal. of storage*	0.02 to 0.03 HP/1,000 gal. of storage*	8
	0.05 to 0.20 ft^3/gal. of storage	9
5 to 8 mg O_2/l-hr. (.04 to .06 cfm/1,000 gal. of storage)		10
	0.07 to 0.16 ft^3/gal.of wastewater	11
	0.1 to 0.4 ft^3/gal. of wastewater	12
	20 cfm/1,000 cu ft of storage*	7

* These values pertain to mixed-liquor in an aerated pond rather than to raw wastewater.

Notes:
(1) cfm/1,000 gal x 0.0074 = m^3/min/m^3
(2) HP/1,000 gal x 0.1975 = kw/m^3
(3) ft^3/gal x 0.0074 = m^3/l
(4) cfm/1,000 cu ft x 0.001 = m^3/min/m^3

It may be observed in Figure V-2 that a sludge scraping mechanism was provided in the Walled Lake/Novi equalization basin. Sludge collection is not necessary if sufficient mixing is provided to prevent solids deposition.

Pumping. Pumping considerations are extremely important in the economic design of a flow equalization system. As discussed earlier in this section, pumping may dictate the choice of the type of system to be used.

The Walled Lake/Novi influent puming station houses six raw wastewater pumps which include three process pumps and three equalization pumps. The process pumps are designed to elevate wastewater at the average daily flow rate; two variable-speed pumps and one constant-speed (stand-by) pump, each with a capacity of 47.3 l/sec (750 gpm), are provided. The equalization pumps are each of 75.7 l/sec (1200 gpm) capacity, with two being variable speed and one constant speed (stand-by pump). These pumps are sized to elevate wastewater in excess of the average daily flow rate. With two equalization pumps in operation, up to 151.4 l/sec (2400 gpm) can be pumped to the equalization basin, which is the estimated difference between the average and maximum daily rates of flow.

Flow Metering. Inclusion of equalization facilities in a plant may require additional flow metering for control purposes. Whether or not additional metering is required will depend on the particular method used to control flow rate to (or from) the equalizaton basin. The Walled Lake/Novi plant has three magnetic flow meters, whose functions are as follows:

1. A 254 mm (10-in.) meter measures the process flow; its function is to indicate that the proper (preset) flow, equal to the average daily flow, is maintained by the process pumps that pump from the influent wet well to the grit chamber.
2. A 304.8 mm (12-in.) meter measures flows which are in excess of the preset flow, such flows being pumped to the equalization tank; this meter has no control function in this plant.
3. A 203.2 mm (8-in.) meter measures the flow from the equalization tank back to the wet well; it is tied to a control valve and functions to compensate for inflow deficiency during periods when the incoming flow is less than average.

Operation and Control

Operation and control of the Walled Lake/Novi equalization facility may be described as follows:

Each morning the average flow expected over the following 24 hours is estimated and process pumps are preset to maintain this rate. When the flow increases, a controller starts an equalization pump to pump the excess flow to the equalization basin.

When incoming flow diminshes to below average, the effluent control valve opens and releases an amount of water from the equalization basin to the wet well, to compensate for the deficiency of the influent. Even when shut, the control valve allows a small portion of liquid to bleed constantly to the wet well to help prevent accumulation of solids on the bottom of the tank.

The control system has functioned well since plant start-up and is capable of maintaining a virtually constant process flow rate. Initially, the operators had difficulty forecasting the average daily flow rate, necessitating overly-frequent and excessively-large adjustments to the process pumping rate. Such adjustments, of course, defeat the purpose of providing flow equalization. As experience has been gained, however, this problem has been largely eliminated.

SECTION VI

EXPERIMENTAL PROCEDURES

Sampling

The experimental program was designed to accomplish the following project objectives: (i) evaluate the performance of the equalization tank with respect to flow and mass leveling and (ii) compare the performance of the plant under equalized and non-equalized conditions.

Budgetary restrictions limited the monitoring program to two weeks' duration in the Fall of 1974*. During the first week (September 30 to October 7) the plant was operated under equalized flow conditions, while during the second week (October 28 to November 3) the equalization basin was removed from service and normal diurnal flow conditions prevailed.

Samples were collected every two hours from the raw wastewater, process influent (i.e., following equalization), secondary clarifier effluent, and filter effluent. All samples were refrigerated upon collection and analyzed the following day.

Analyses

Samples were analyzed for BOD_5, TSS, SOP, and NH_3-N. All analyses were performed in accordance with the 13th Edition of Standard Methods. Dissolved orthophosphate analyses were performed using the automated colorimetric ascorbic acid reduction method, while ammonia nitrogen measurements utilized the automated colorimetric phenate method.

Plant Operation

Prior to the start of the equalized flow testing week, the equalization tank was emptied to maximize the available storage volume. Thereafter, no further adjustments were made to the flow rate control system and the tank level was permitted to fluctuate freely. In this way, a virtually constant flow rate was maintained throughout the 7-day testing period.

*Another week of intensive sampling was also conducted during the Summer of 1974; however, because of operational difficulties, the data have not been analyzed.

The multimedia filters were backwashed just prior to the start of each testing period. No further backwashing was required during the duration of either the equalized or the unequalized testing periods.

SECTION VII

RESULTS AND DISCUSSION

Performance of Equalization Basin

Flow Leveling. The Walled Lake/Novi equalization system is highly effective in leveling influent flow variations and providing a uniform flow rate to the process units. Its effectiveness is documented by the plant flow charts; a smooth flow curve is generated which, with proper system operation, typically shows a constant flow rate throughout each day. Figure VII-1 gives representative portions of actual plant flow charts from the testing period.

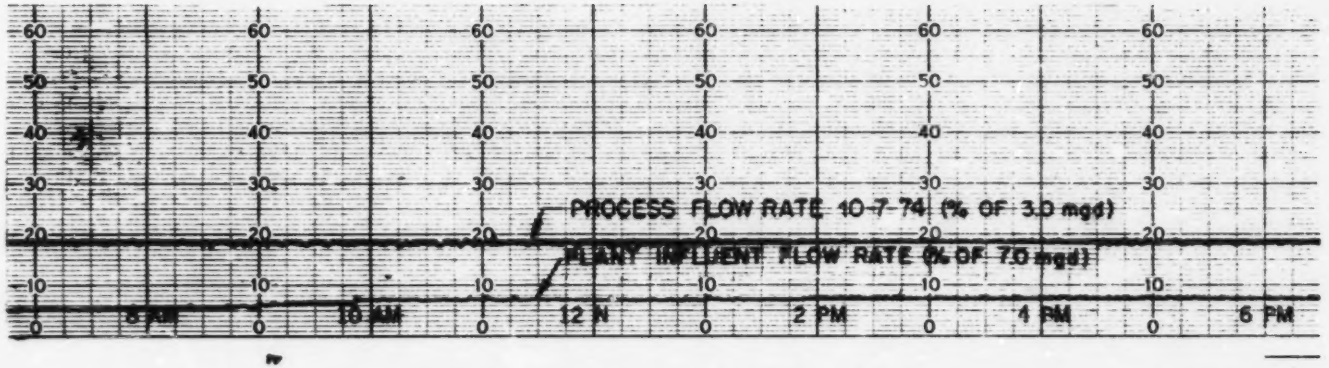
Concentration Leveling. Data illustrating concentration leveling effected by the flow equalization system are presented in Figure VII-2. Concentrations of various constituents are plotted as a function of time for both the raw wastewater and the process (equalized) flow to the aeration basin. As may be noted, equalization had marginal impact on the concentration of these wastewater parameters. Some dampening of BOD_5 and TSS concentrations is evident but, in general, both the raw and equalized wastewater exhibited similar diurnal variations in strength.

In a side-line equalization system, concentration leveling is expected to occur only during low-flow periods when the tank is emptying its stored contents. At such times, the constituent concentrations in the released volume are likely to be higher than in the raw wastewater, thereby raising the concentration in the mixture. Conversely, during peak flow periods, very little flow is released from the equalization basin and concentration damping cannot occur.

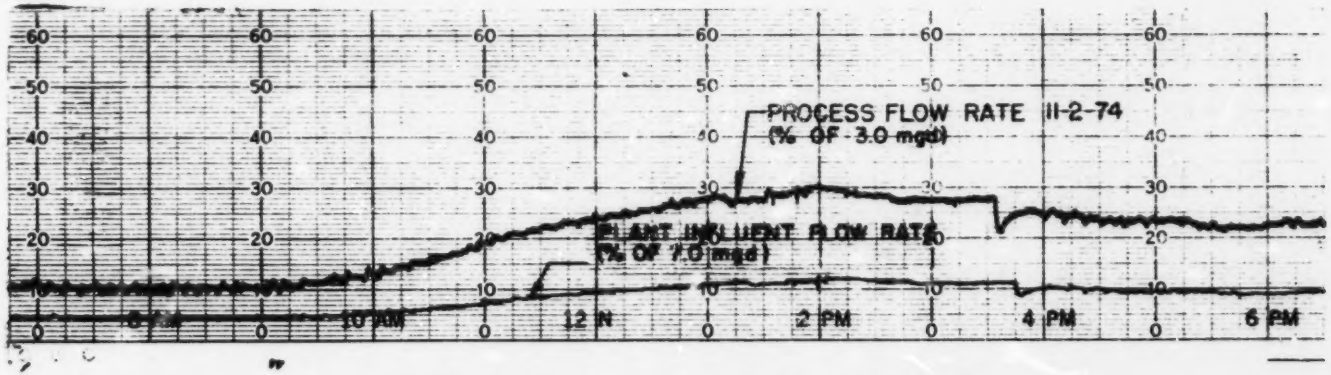
Mass Leveling. Side-line flow equalizaton necessarily accomplishes some mass leveling even though it is fairly ineffective in concentration leveling. The mass leveling occurs primarily because the flow rate is equalized, not because any blending occurs. Figure VII-3 illustrates the mass leveling that occurred during the testing period.

Effects of Equalization on Influent Wastewater Characteristics

It was not within the scope of the study to adequately characterize the changes in wastewater characteristics produced by biological action in the equalization



A. PORTION FROM EQUALIZED FLOW PERIOD



B. PORTION FROM UN-EQUALIZED FLOW PERIOD

FIGURE VII-1. TREATMENT PLANT FLOW CHARTS - WALLED LAKE/NOVI, MICHIGAN

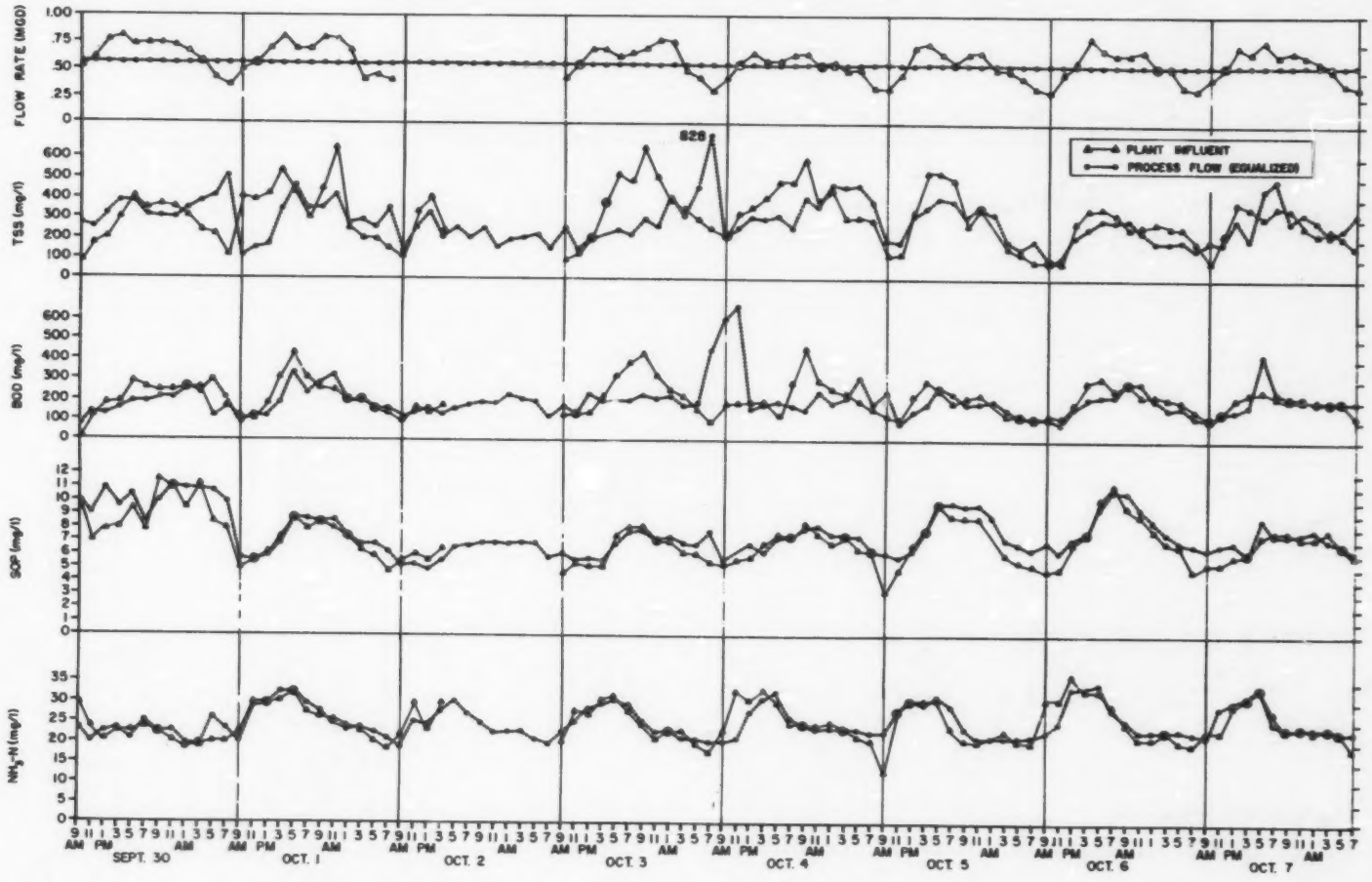


FIGURE VII-2. EFFECTS OF EQUALIZATION ON CONCENTRATION LEVELING

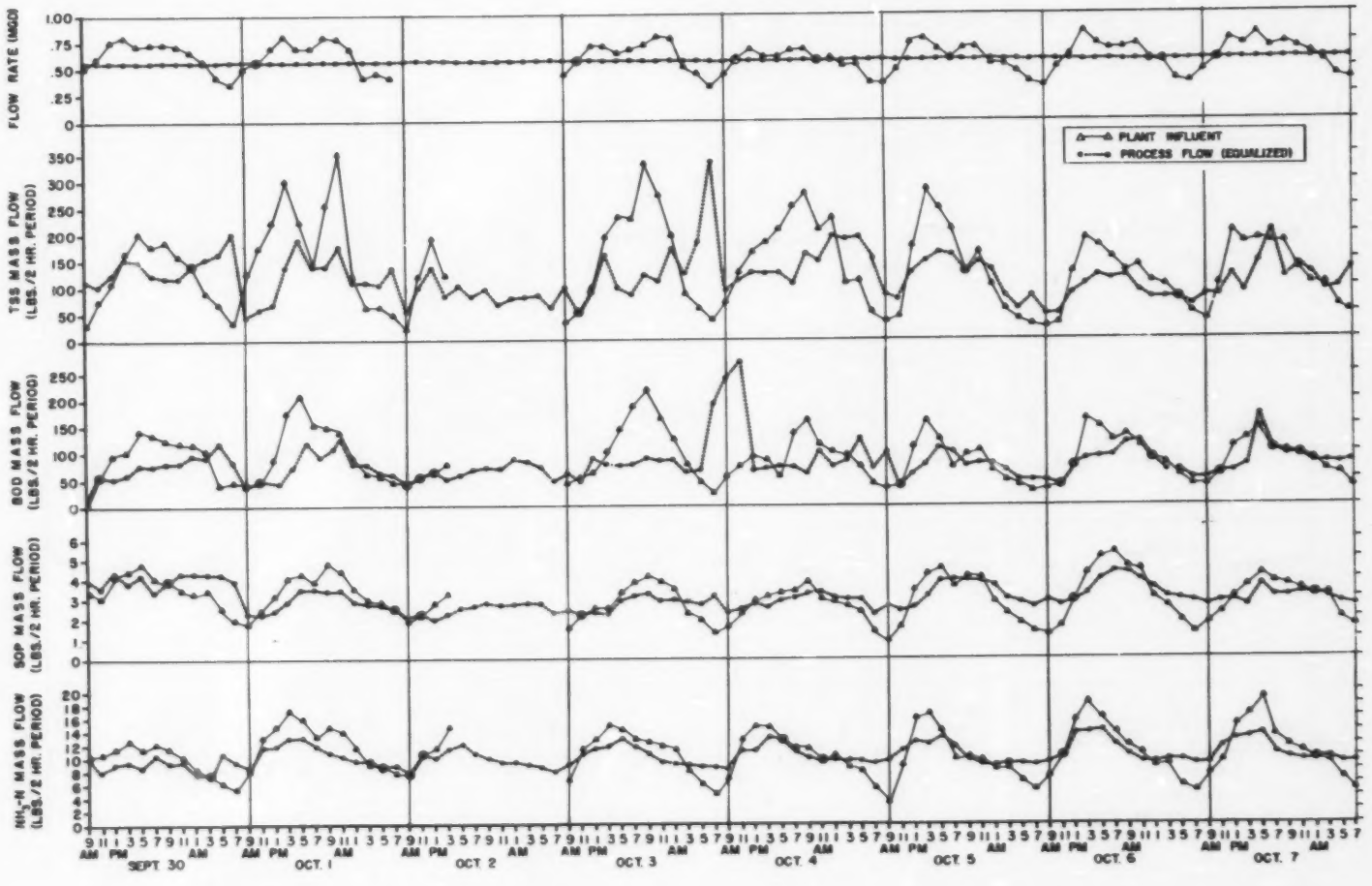


FIGURE VII-3. EFFECTS OF EQUALIZATION ON MASS LEVELING

tank. The limited available data are summarized in Table VII-1, which is essentially a mass balance for each of the constituents studies. The individual parameters are discussed in the following paragraphs.

TABLE VII-1

EFFECTS OF EQUALIZATION ON WASTEWATER PARAMETERS

Parameter	Average Content During Testing Period (lbs/day)* Raw (Unequalized) Wastewater	Process (Equalized) Wastewater	% Change
TSS	1610	1420	-11.8
BOD_5	1080	970	-10.2
SOP	36.3	36.9	+1.7
NH_3-N	125	119	-4.8

*Testing Period was 9/30; 10/1, 2, 3, 4, 5, 7 (1974).
lb/day x 0.4536 = kg/day.

Total Suspended Solids (TSS). The data indicate that the mass of TSS in the equalized wastewater was 11.8 percent less than that in the raw wastewater over the testing period. A reduction in TSS is opposite to what would be expected if growth of biomass occurred in the equalization basin. It is likely that solids deposition occurred in the basin resulting in some accumulation of sludge. While an attempt was made to avoid sludge accumulation by continuously bleeding a small amount of flow from the bottom of the basin, there was no way of knowing how successful this operation was. Unfortunately, long-term data are not available because the equalized flow is not sampled by treatment plant personnel. We believe such long-term data is necessary before meaningful conclusions can be drawn.

Biochemical Oxygen Demand. There was an apparent 10.2 percent overall BOD_5 reduction effected by the equalization tank during the 7-day testing period. This percentage is higher than would be expected for a side-line equalization system in which only about 15 percent of the flow is diverted through the equalization basin. Most of this reduction can probably also be attributed to deposition and accumulation of solids in the basin.

Soluble Orthophosphate (SOP). Over the 7-day period, the mass flow of SOP for the equalized wastewater was almost equal to that for the raw wastewater.

Because any change in SOP would be expected to be small, a longer sampling period would be needed to establish a definitive trend.

NH_3-N. The data show that there was an average overall reduction in ammonia nitrogen, but the change was generally negligible.

Effects of Equalization on Plant Processes

To determine the effects of equalization on plant treatment processes, intensive testing was conducted on each process stream with and without flow equalization. Table VII-2 presents a tabular summary of the results, which are discussed in detail below, and Table VII-3 lists values for some of the pertinent operating parameters for the study periods.

From Tables VII-2 and VII-3, some general observations can be made regarding the experimental conditions that prevailed during the two week-long testing periods. The average plant flow rates were virtually identical during each testing period and the plant influent characteristics were likewise very similar, except that the TSS concentration was 32 percent (80 mg/l) higher during the equalized week. Aeration basin operating parameters were also very similar, except that the organic loading (F/M ratio)was somewhat higher during non-equalized operation. Hydraulic loadings for final clarification and filtration, respectively, were essentially the same during the two testing periods; moreover, both of these processes were underloaded.

Activated Sludge - Final Settling. The mean performance values presented in Table VII-2 reveal that secondary clarifier effluent quality with respect to TSS content was actually somewhat poorer during equalized flow than it was during the week in which diurnal flow variations prevailed. For the other parameters, the secondary clarifier effluent quality was slightly better during the equalized flow period. These differences can be more clearly observed in the graphical presentation of data in Figure VII-4, in which cumulative mass in the clarifier effluent during the testing periods is plotted as a function of time for each of the parameters studied. Close observation of the curves in Figure VII-4 show the following:

1. TSS - Over the respective 7-day periods, the total poundage of TSS that escaped in the final clarifier effluent during equalized flow was 240 kg (530 lb) versus only 133 kg (293 lb) during non-equalized flow. Considering the low clarifier overflow rates in effect during the study

TABLE VII-2

PLANT PERFORMANCE SUMMARY

WALLED LAKE/NOVI, MICHIGAN

Parameter (avg. value)	Equalized Period[1]				Non-equalized Period[2]		
	Plant Influent	After Equalization	Clarifier Effluent	Filter Effluent	Plant Influent	Clarifier Effluent	Filter Effluent
Flow Rate (mgd)	0.592	0.574	0.574	0.574	0.585	0.585	0.585
BOD							
mg/l	219	203	10	4	243	14	7
lb/day	1080	971	48	19	1185	67	33
TSS							
mg/l	326	296	17	3	246	9	6
lb/day	1609	1417	83	16	1200	42	29
SOP							
mg/l	7.4	7.7	1.2	1.3	7.6	1.3	1.5
lb/day	36.3	36.9	5.8	6.1	36.9	6.5	7.1
NH_3-N							
mg/l	25.5	24.9	0.6	0.5	27.5	1.8	1.3
lb/day	125.5	119.0	3.0	2.5	134.0	8.9	6.4

[1] 9/30; 10/1, 3, 4, 5, 6, 7 (1974).
[2] 10/28, 29, 30, 31; 11/1, 2, 3 (1974).

Notes: (1) Values shown are the averages for the testing period.
(2) 1b/day x 0.4536 = kg/day
(3) mgd x 0.04381 = m^3/sec
(4) During the equalized period, average flow rate after equalization was less than that for the plant influent, indicating some accumulation of wastewater in the equalization basin.

TABLE VII-3

SUMMARY OF OPERATING PARAMETERS
DURING TESTING PERIODS
WALLED LAKE/NOVI, MICHIGAN

	Equalized[1] Operation	Non-Equalized[2] Operation
Aeration		
Flow Rate (mgd)	0.574	0.585
MLSS (mg/1)	2,412	2,271
MLVSS (mg/1)	1,513	1,479
SDI	2.6	2.2
F/M	0.40	0.52
Sludge Age[3] (days)	6.8	5.1
D.O. in Tanks (mg/1)	4.5	3.7
Detention Time without recycle (hrs.)	10.6	10.4
Final Settling		
Overflow Rate (gpd/sq ft)	292	298
(m^3/m^2 day)	11.9	12.1
Filtration		
Filter Rate (gpm/sq.ft.)	1.0	1.0
(m^3/m^2 day)	58.7	58.7

[1] 9/30; 10/1, 3, 4, 5, 6, 7 (1974).
[2] 10/28, 29, 30, 31; 11/1, 2, 3 (1974).
[3] Computed as shown in Table IV-5

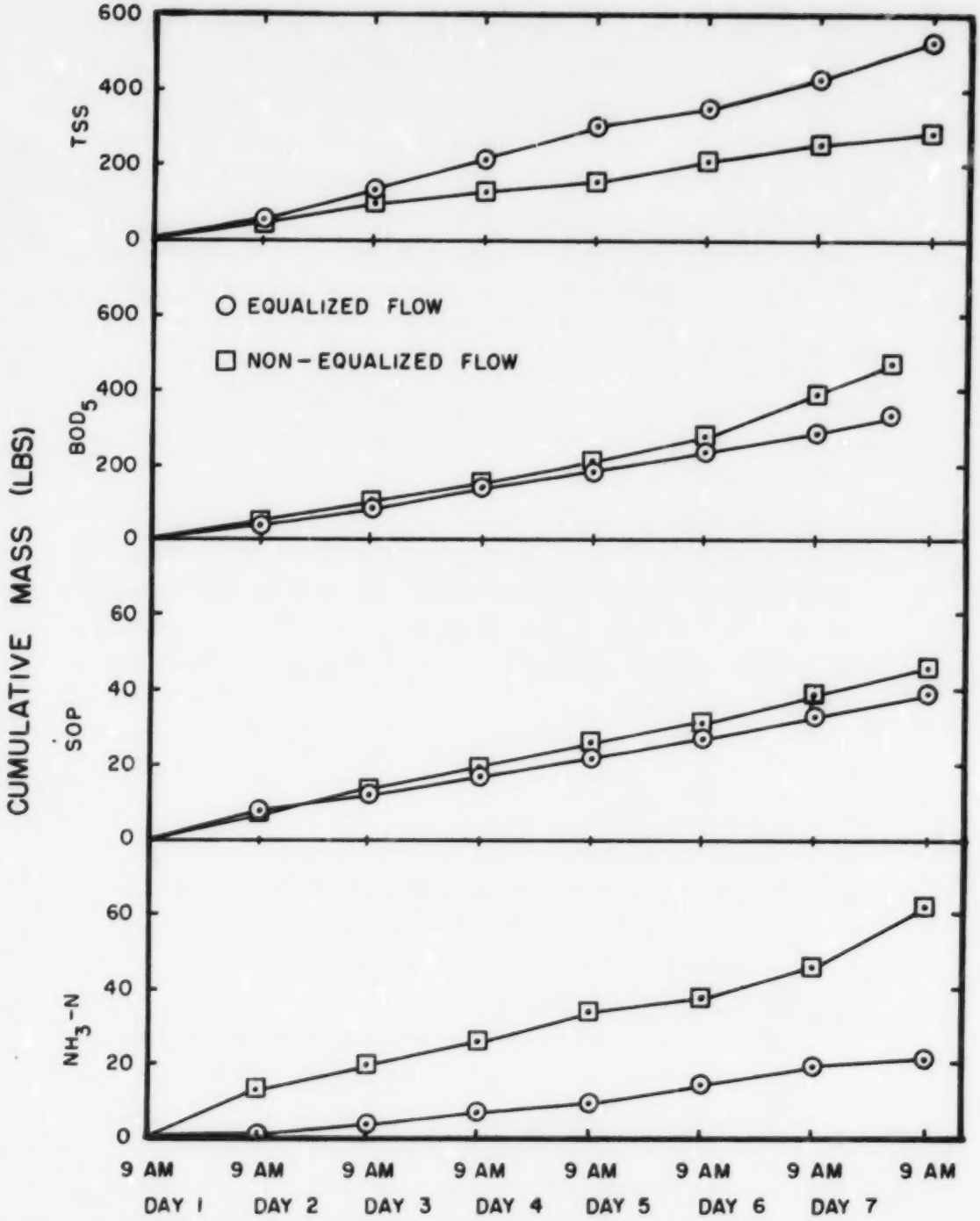


FIGURE VII-4. MASS DIAGRAM - FINAL CLARIFIER EFFLUENT
(lbs x 0.4536 = kg)

periods, this difference is considered to be due to factors such as minor differences in sludge settleability, lack of adequate control of sludge blanket height in the final clarifier, wind and density currents, etc. Based upon percentage removal, performance was actually very similar for the two periods (95.3 and 96.5 percent for the equalized and non-equalized flow periods, respectively).

2. BOD_5 - 166 kg (366 lb) of BOD_5 escaped in the secondary effluent during the equalized flow period as compared to 211 kg (466 lb) during the non-equalized flow period. It should be noted that BOD_5 removal was better during equalized flow even though TSS removal was worse during the same period. This anomalous result indicates that the solids escaping in the clarifier effluent during equalized flow were either more stabilized due to lower F/M ratios or were of an inorganic nature.
3. SOP - With respect to SOP, 18 kg (39 lb) carried over in the clarifier effluent during the equalized flow period versus 21 kg (46 lb) during unequalized flow. Thus, soluble phosphorus removal was only marginally better under equalized flow conditions, a result which is not unexpected with a side-line flow equalization system which does not produce concentration dampening. This can be better understood by considering what takes place when Al (or Fe) is applied in equalized versus unequalized systems (assuming that in both cases chemical feeders are paced to flow for dosage control):
    a. Under diurnal flow conditions, the mass flow rate of applied Al will vary diurnally, but the concentration of Al applied will be constant through the day; this means that the weight ratio of Al:P will necessarily vary diurnally since the P concentration in the wastewater varies diurnally.
    b. Under equalized flow conditions, the mass flow rate of applied Al will be constant through the day as will the concentration of Al applied to the wastewater; however, the weight ratio of Al:P will vary diurnally just as in the unequalized case.

    Thus, under either equalized or unequalized flow conditions, the Al:P ratio will vary as the P concentration in the wastewater varies.
4. NH_3-N - The curve shows that 10 kg (21 lb) of NH_3-N escaped in the secondary effluent during equalized flow conditions as contrasted

to 28 kg (62 lb) during the non-equalized flow period. Expressed as percentage removal, the results were 97.6 and 93.5 percent, respectively. These high NH_3-N removals in the plant are presumably due to the use of a long solids retention time (SRT) although the data did not permit computation of SRT's. The greater NH_3-N removal during equalized flow may be due to a greater SRT rather than to the effects of equalization.

The preceding discussion is concerned primarily with comparing the average values obtained during equalized flow with those obtained under non-equalized conditions. It is also interesting to observe the "scatter" about the means. Figure VII-5 shows frequency histograms for bi-hourly samples taken on secondary effluent during the testing periods. These histograms indicate that TSS removal was not only poorer but also showed greater variance under equalized flow conditions; however, BOD_5 removal was slightly better and somewhat more consistent with equalized flow.

All of the preceding discussion suggests that, for the underloaded final clarifier, variations in flow rate were not as important as other variables in determining removal efficiency. Accordingly, TSS concentrations in grab samples of secondary effluent did not correlate very well with the clarifier overflow rate at the time of sampling, for samples collected under diurnal flow conditions. Thus, the sensitivity of the activated sludge-final settling processes to flow rate variations may not become apparent until they are stressed to higher loadings than occurred in this study. Prior to the point at which a secondary clarifier is hydraulically stressed, factors such as solids loading, wind and density currents, and bio-floc settleability may dictate performance; settleability, in turn, is dependent on F/M, aeration basin agitation, chemical dose (for P precipitation) and other factors.

Filtration. The data summary in Table VII-2 shows that filter effluent quality was better under equalized flow conditions for each of the parameters studied. Moreover, the higher TSS removal was achieved even though the filter influent TSS concentration was higher and more variable during the equalized flow period.

A further comparison of filter performance under equalized and non-equalized flow conditions is illustrated graphically in Figure VII-6. The curves for each parameter are discussed individually below.

1. TSS - The total poundage of TSS that escaped in the filter effluent during the non-equalized flow period was 93 kg (205 lb) as opposed

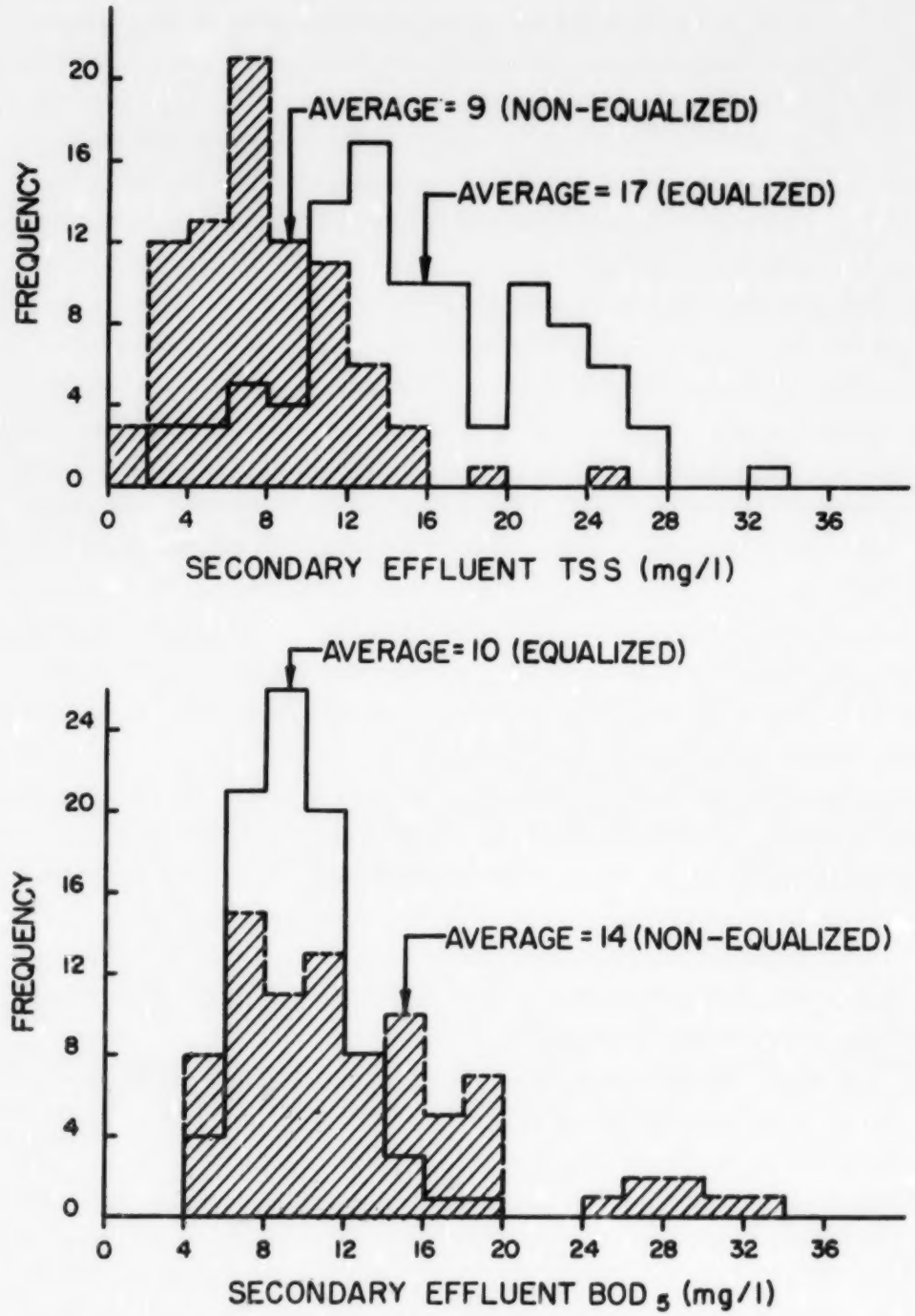


FIGURE VII-5. EFFECT OF EQUALIZATION ON SECONDARY EFFLUENT BOD_5 AND TSS

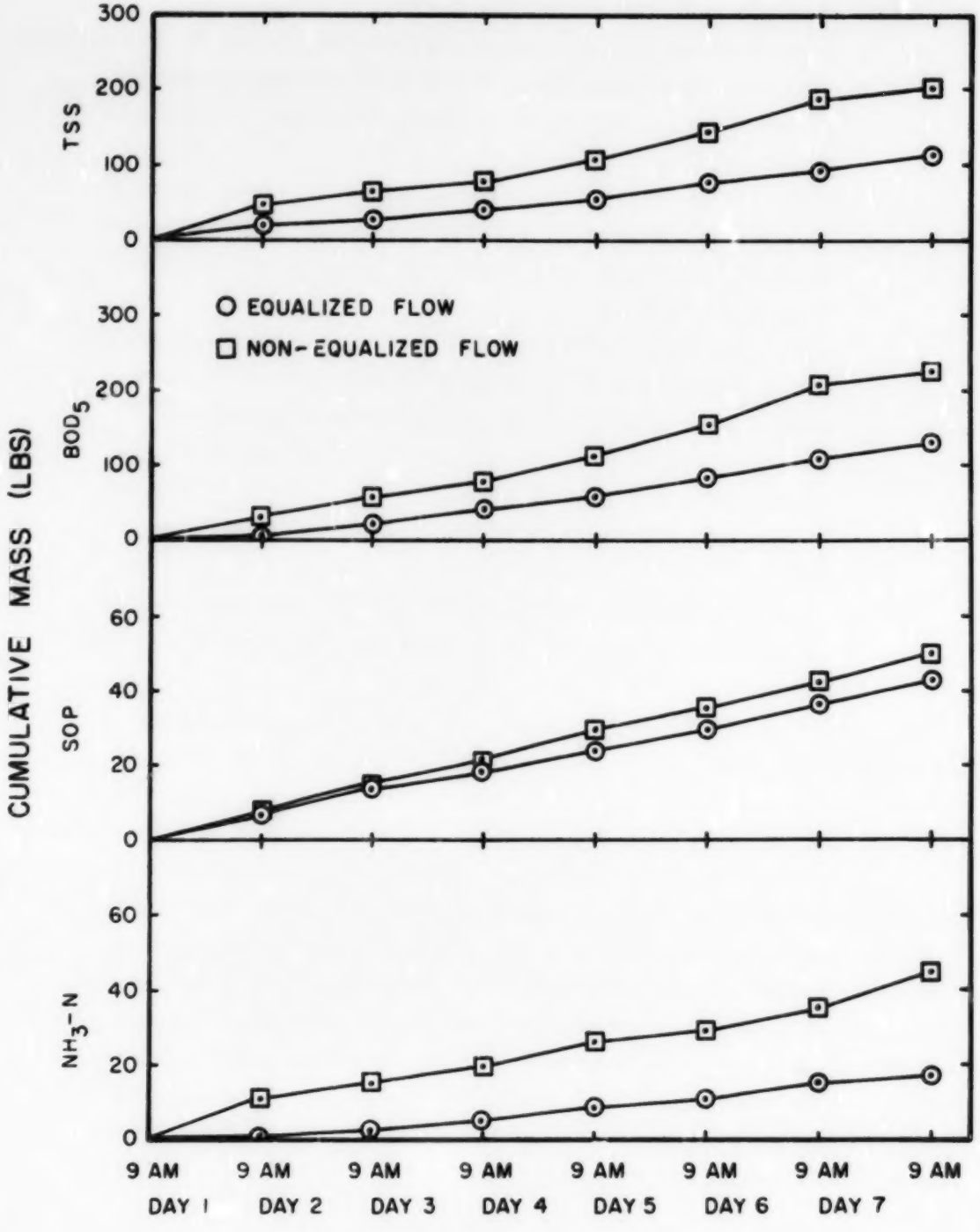


FIGURE VII-6. MASS DIAGRAM - FILTER EFFLUENT (lbs x 0.4536 = kg)

to only 51 kg (112 lb) during equalized flow. The higher performance under equalized flow is even more apparent when the results are compared on a percentage removal basis. During equalized flow, 82 percent of the TSS was removed across the filters versus only 33 percent during the non-equalized flow period.

2. BOD_5 - 60 kg (132 lb) of BOD_5 carried through the filters during the equalized flow period as compared to 103 kg (226 lb) during the non-equalized flow period. These values represented 61 and 52 percent removal, respectively.
3. SOP - During equalized operation, 20 kg (43 lb) of SOP penetrated the filters, while the figure was 23 kg (50 lb) under diurnal flow conditions. Both of these values are slightly higher than the respective filter influent content of SOP, but the change is insignificant. Also, the monthly plant data, summarized previously in Table IV-4 shows that there is an overall reduction in total P across the filters.
4. NH_3-N - The data show that 8 kg (18 lb) of NH_3-N escaped in the filter effluent during equalized flow conditions in contrast to 20 kg (45 lb) during the non-equalized flow period. There was very marginal removal across the filter in both cases.

To observe the scatter in the filter effluent data, frequency histograms were again constructed from the bi-hourly TSS and BOD_5 data. The results are depicted in Figure VII-7 which shows that filter performance was somewhat better under equalized operation, both in terms of average removal efficiency and consistency.

The results of these experiments tend to support the generally held belief that granular media filters should be operated at a constant rate. However, the filters in these studies were run at the low average rate of only 58.7 m^3/m^2 day (1 gpm/sq ft), thus making it questionable whether the better performance under equalized flow conditions can be attributed solely to the benefits of steady flow. Further work is needed to evaluate the effects of transient hydraulic and solids loading on filter performance. It is possible, for example, that some particles removed during low flow-low shear conditions in a filter may be dislodged as the flow rate increases, even at low average filter rates.

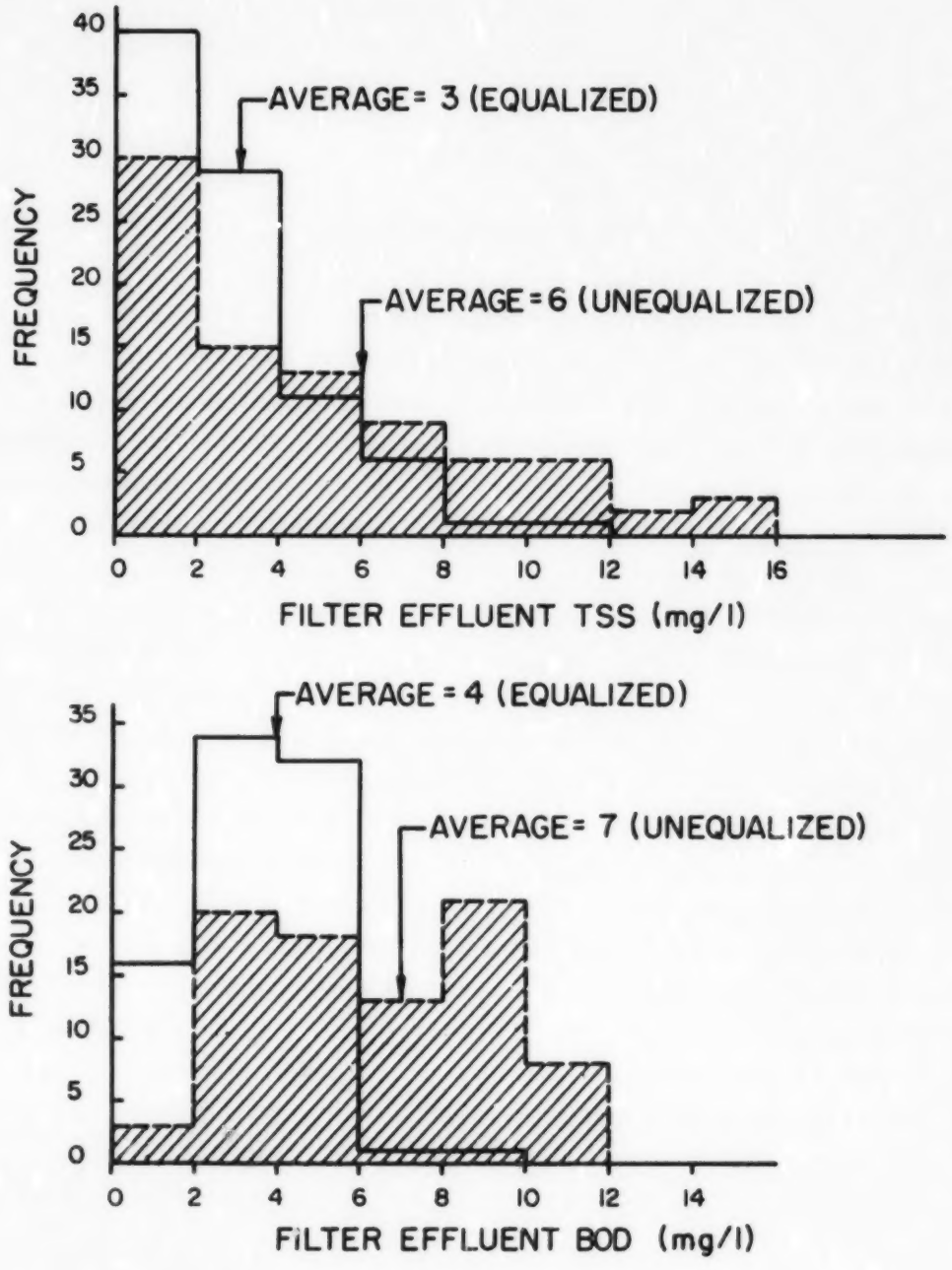


FIGURE VII-7. EFFECT OF EQUALIZATION ON FILTER EFFLUENT BOD_5 AND TSS

SECTION VIII

COST CONSIDERATIONS

General

The major cost components of an equalization system are those of the basin, mechanical or diffused aeration system, pumping, and flow measurement. The economic basis for bearing the additional costs of these components rests upon the presumption that treatment units are indeed affected by diurnal flow variations. If this presumption is true, then cost savings can result by providing equalization and designing process units based on the average flow instead of the peak flow.*

The results of this limited research program have shown that BOD_5 and suspended solids removals through the final settling process were not significantly different with and without equalization, while the final settler was underloaded. From the discussion in Section VII, any differences between equalized and unequalized flow (through final clarification) appeared to be explainable in terms of factors other than just the presence or absence of flow rate variations. However, it must be emphasized again that the aeration basins and final settler at the Walled Lake/Novi Wastewater Treatment Plant operated well within their design capacity throughout the study. The maximum 2-hour overflow rate on the final clarifier, for example, was less than 20 m^3/m^2 day (500 gpd/sq ft) during the testing period. It is to be expected that an underloaded clarifier would not be very sensitive to flow-rate variations. If the clarifier had been stressed, the effect of diurnal variations in flow might well have been significant.

On the other hand, filter performance in this study seemed to react to flow rate variations. This result occurred even though the filters were not stressed, indicating that the absolute value of the filter rate may perhaps be even

*It is not always recognized that diurnal flow variations are implicitly incorporated into most of the loading factors used to size treatment units. Hence, the design is actually based on the peak flow even though the average flow is used in the computation.

less important than whether or not there are variations in rate. Further research is warranted to evaluate the effects of diurnal hydraulic and solids loadings on filter performance.

Equalization Basin

The actual construction cost of the Walled Lake/Novi equalization basin is given in Table VIII-1; construction costs for the wastewater treatment plant as a whole are presented in Table VIII-2. It may be seen that the cost of the equalization tank and appurtenances was $143,000 (EPA Index 172). This amount includes $40,000 for sludge scraping equipment which has proven unnecessary. If the cost of sludge scraping is excluded, the equalization system comprised between 6 and 7 percent of the total construction cost of this tertiary treatment plant.

Pumping

Plant pumping costs, including both the initial cost of the pumps and their operating costs, will usually be higher if flow equalization is provided. However, the difference may not be as great as imagined because: (i) constant flow conditions reduce peak pumping demands and, hence, the requisite size of motors; and (ii) pumps designed for constant flow can operate continually at a more efficient point on their operating curve.

We have computed, for purposes of illustration, the theoretical power costs for pumping at the Walled Lake/Novi plant with and without flow equalization. The following assumptions were made:

1. Plant flow is at the design rate of 2.1 mgd, with diurnal variations as shown in Figure V-3.
2. Power costs are $0.0124/kwh for the energy charge and $3.85/kw-month for the demand charge (based on January 1975 rate schedule).
3. The combined pump and motor efficiency is 0.6 and is uniform at all pumping rates.

Under equalized flow, it was found that the peak hourly power demand for pumping would be 33.4 kw and the total daily energy requirement would be 647 kwh, resulting in a daily power cost of $12.31. With the same flow, but without equalization, the computed daily power cost is $12.10/day, based upon a peak hourly demand of 37 kw and a daily energy requirement of 594 kwh. Thus, the additional power cost due to equalization is only $0.21/day or less than $80.00 per year.

It is concluded that power rate schedules which penalize peak demands with a high demand charge may improve the cost effectiveness of flow equalization.

TABLE VIII-1

CONSTRUCTION COST

WALLED LAKE/NOVI EQUALIZATION BASIN*

Item	Cost
Excavation	$10,000
Mud Mat	2,000
Foundations	7,000
Slab	6,000
Form Walls	20,000
Pour Walls	6,000
Grout	2,000
Pumps, Motors & Controls	28,000
Instrumentation	15,000
Air Piping & Compressor	3,000
Exterior Piping	4,000
Sludge Scraping	40,000
TOTAL (with sludge scraping)	$143,000
TOTAL (without sludge scraping)**	$103,000

* Based on final construction cost breakdown; does not include land costs, engineering fees, or interest during construction. The bid opening was in January, 1971; construction was completed in mid 1972 (EPA Index 172).

** Sludge scraping equipment is not needed if sufficient mixing is provided.

Note: Basin Storage Volume = 1,275.5 m^3 (337,000 gal).

TABLE VIII-2

CONSTRUCTION COST

WALLED LAKE/NOVI WASTEWATER TREATMENT PLANT*

Item	Cost
Move-in & Cleanup	$ 12,000
Comminutor	7,000
Process Equipment, Treatment Tanks & Chlorine Contact Chamber	431,000
Influent Pumping Station	187,000
Equalization Tank**	93,000
Grit Chamber	23,000
Filters & Filter Building	265,000
Sludge Drying Beds	94,000
Process Piping, Fittings & Valves	152,000
Pumps, Motors & Controls	58,000
Instrumentation	83,000
Electrical	112,000
Administration Building	24,000
Fencing, Sidewalks & Landscaping	22,000
Miscellaneous Site Work	75,000
Access Road	43,000
Bond & Overhead	28,000
TOTAL	$1,709,000

* Based on final construction cost breakdown; does not include land costs or engineering fees. The bid opening was in January, 1971 construction was completed in mid-1972 (EPA Index 172).

** Cost does not include pumps, instrumentation, air supply or exterior piping; costs for these components are included in other items.

It is possible that, in some instances, power costs for pumping will be less with equalized flow than they would be without it.

Aeration

Aside from pumping, power costs for aeration and mixing provide the major operating expenditure for an equalization basin. At Walled Lake/Novi, 17.6 m^3/min (630 cfm) of blower capacity is assigned to the equalization basin. This amount represents 10.8 percent of the calculated air requirement for the total plant at design flow.*

Theoretically, provision of flow equalization could reduce the peak aeration demand in the biological unit by leveling the mass flow of BOD_5 to the unit and, perhaps, by accomplishing some BOD_5 reduction itself. This would mean smaller requisite blower capacity for the biological unit and also reduce demand charges for power. If automated dissolved oxygen control is provided for the aeration basin, the savings in aeration costs imparted to the biological unit would offset in part or in total the added costs of aerating the equalization basin.

Power consumption data recorded at the Walled Lake/Novi plant during the two week-long test periods shows that total power usage was 35,400 kwh during the equalized flow period and 34,560 kwh under unequalized flow conditions; thus, total consumption was 2.4 percent higher during equalized operation. Similarly, the peak daily usage was 5670 kwh during equalized flow and 5460 kwh during unequalized operaton. These figures do not necessarily demonstrate that the equalized mode has a greater power demand since no automated facilities were available to optimize air usage during the study. In fact, there is some indication that the biological unit was over-aerated during the equalized flow period since daily dissolved oxygen measurements of the mixed liquor averaged 4.5 mg/l versus only 3.7 mg/l during unequalized operation. Moreover, as mentioned previously, the equalization basin at the plant is prone to use an excessive amount of power because controls were not designed to reduce the air flow when the liquid level in the basin drops. There, observations again indicate that automated control are necessary to gain the full potential of flow equalization.

*Aeration capacity assigned to other units is as follows: Aeration basins, 104.2 m^3/min (3720 cfm); aerobic digester, 47.0 m^3/min (1680 cfm); and aerated grit chamber, 2.1 m^3/min (75 cfm).

Chemical Feeding

With regard to chemical feeding for phosphorus removal, experience at the Walled Lake/Novi Wastewater Treatment Plant indicates that equalization may not necessarily provide the commonly ascribed benefits of reduced capital costs and simpler control. For example, the chemical feed system at Walled Lake/Novi was designed to provide the same degree of automatic control that would have been provided for a plant with diurnal flow. It must be remembered that a flow equalization system does not guarantee uniform flow from one day to the next; periodic adjustments in the equalized flow rate are necessary due to daily and seasonal variations in flow. Thus, the ability to automatically pace chemical dose to flow is desirable even with flow equalization in order to eliminate the need for manual readjustment in chemical pumping rates whenever the equalized flow rate is changed. In addition, the presence of equalization does not reduce the operational requirements for checking influent P concentration (which can vary from day to day) and adjusting the chemical dose according.

Manpower Requirements

It is clear that equalization must produce added manpower requirements for operation and maintenance at a plant because of the additional equipment and controls. It is the authors' observation that a negligible amount of operator time is required on a day-to-day basis for routine maintenance and operation. The major requirements will be for equipment repair. After three years of operation at Walled Lake/Novi, the only significant equipment failure has been in the flow metering system.

SECTION IX

REFERENCES

1. La Grega, M. D., and Keenan, J. D., "Effects of Equalizing Wastewater Flows," Jour. Water Poll. Control Fed., 46, 123 (1974).
2. Wallace, A. T., "Analysis of Equalization Basins, "Proc. Amer. Soc. Civil Engr., Jour. of the Sanitary Engr. Div., SA6, 1161 (1968).
3. Spiegel, M., "Flow Equalization to Ensure Designed Wastewater Treatment at Lowest Cost, "The Diplomat, Amer. Academy Environ. Engrs., p. 3-6 (May, 1974).
4. Flow Equalization, Technology Transfer Seminar Publication, U.S. Environ. Protection Agency, 21 pp. (May, 1974).
5. Boon, A. G., and Burgess, D. R., "Effects of Diurnal Variations in Flow of Settled Sewage on the Performance of High Rate Activated Sludge Plants," Water Poll. Control (Gr. Britain), 71, 493-522 (1972).
6. Process Design Manual for Suspended Solids Removal, Technology Transfer Office, U. S. Environ. Protection Agency, Cincinnati, OH (January, 1975).
7. Smith, R., Eilers, R. G., and Hall, E. D., "Design and Simulation of Equalization Basins," U. S. Environ. Protection Agency, Office of Research and Monitoring, Advanced Waste Treatment Research Laboratory, Cincinnati, OH (Feb., 1973.)
8. Eckenfelder, W. W., Water Quality for Practicing Engineers, Barnes and Noble, Inc., New York (1970), p. 148.
9. Clark, J. W., Viessman, W., Jr., and Hammer, M. J., Water Supply and Pollution Control. 2nd Edition, International Textbook Co., Scranton, PA (1971), p. 355.
10. Seidel, H. F., and Baumann, E. R., "Effect of Preaeration on the Primary Treatment of Sewage," Jour. Water Poll. Control Fed., 33, 339 (1961).
11. Roe, F. C., "Preaeration and Air Flocculation," Sewage Works Jour., 23, 2, 127 (1951).
12. Wastewater Engineering, Metcalf and Eddy, Inc., McGraw-Hill Book Co., New York (1972).